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Agent-based simulation on the effect of policies on long-term energy conservation at an area level

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Abstract. Japan has promoted energy saving in commercial buildings through various policies such as mandatory standards for energy performance, spread of energy labelling, and relevant subsidies. For more efficient policy making, we need to know which measures are effective and how those measures should be combined. We aim to predict the effects of energy saving policies on long-term energy conservation at an area level. This study presents an agent-based simulation model which is composed of building owner agents (OA) and tenant agents (TA). This model can simulate interacts of agents in the area, where OA adjusts the rent for a building and makes a decision for retrofits, and TA moves into a building that maximize its benefits. In the simulation process, we consider not only a positive effect of policy implementation, e.g. energy conservation, but also negative effects: a risk of reducing attractiveness of the area. Therefore, in this paper, we set up an external area in addition to the mainly observed area where simulation is carried out and considered more feasible policies which prevent building tenants from moving to the external area. As a result, we found some important conclusions to achieve both growth of the area and energy conservation.

1. Introduction

Today, global warming is an urgent issue to be solved in the world. As each country has set goals for reducing greenhouse gases in the Paris Agreement[1], the goal in Japanese government is to reduce CO₂ emissions in 2030 by 26% from 2013 [2]. However, contrary to the goal, the proportion of energy consumption tends to increase in the building sector. Therefore, energy saving in building sector is very important to achieve the goal. Japanese government has enforced “the Act on the Improvement of Energy Consumption Performance of Buildings (the Building Energy Efficiency Act)” in 2015 [3]. There are 2 kinds of measures in this act. One is regulatory measures, which obliges new buildings to comply with the energy efficiency standard. Meanwhile, as incentive measures, they try to add incentives for energy-efficient buildings by spreading a labelling system called Building-housing Energy-efficiency Labelling System (BELS). In addition, the national and local governments support the introduction of energy saving equipment with some kinds of subsidies. we cannot estimate the effect of these policies on simple formulas because combinations of these measures can interact with each other. Therefore, in order to grasp the effect of current policies and realize more effective policies, it is necessary to predict the effect of the policies, using a more specific social structure model. There are several studies on energy policies in the building sector.

For example, Erik Porse et al. investigated building energy consumption based on various factors such as the structure, geography, social environment of buildings in Los Angeles for an efficient political



decision [4]. Although this research is for efficient policy decision of the building division and provides important information on building energy demand, concrete policy evaluation is not carried out.

Beijia Huang et al. studied energy conservation policies of Japanese and Chinese buildings based on past literature and interviews with stakeholders [5]. Although this suggests main factors that disturb energy saving and its solutions, quantitative consideration has not been made yet on how much energy demand decreases. Although these studies investigate building energy policies, few studies mention the spread of green buildings. Therefore, in this research, we will present prediction of penetration of green building by the energy policy. We use agent-based simulation described below to model the decision making of building owners' retrofit, rebuilding and tenants' moving in and out. Then we investigated how the energy policies are affecting those decision makings. We also conducted a case study to investigate measures to promote green buildings.

2. Methodology

In this research, a method called agent-based simulation was used. This is a bottom-up simulation that can be used mainly when a group of people or elements creates a complicated phenomenon as a result of interaction between these elements [6]. There are some previous studies on energy policies using agent-based simulation.

Chris Silvia et al. investigates the impact of policies on the introduction of plug-in electric vehicles through a method of agent-based simulation [7]. From this study, we can know that agent-based simulation is suitable for analyzing spread of green technology, but the target is not buildings.

Xin Liang et al. studied the effectiveness of building energy policies through agent-based model, but its main agents are government and building owners, so the building owner and tenant's decision-making process in rental buildings is not taken into consideration [8].

As introduced so far, agent-based simulation is a suitable way for studying energy policy in social model, and it can be applied to the building sector as well.

Figure 1. is a flow diagram of our model. In this research, we recognized the phenomenon that tenants select and move a new lease building as a complex system suitable for agent-based simulation and set up two types of agents in the model; Building owner agent (OA) and tenant agent (TA) [9].

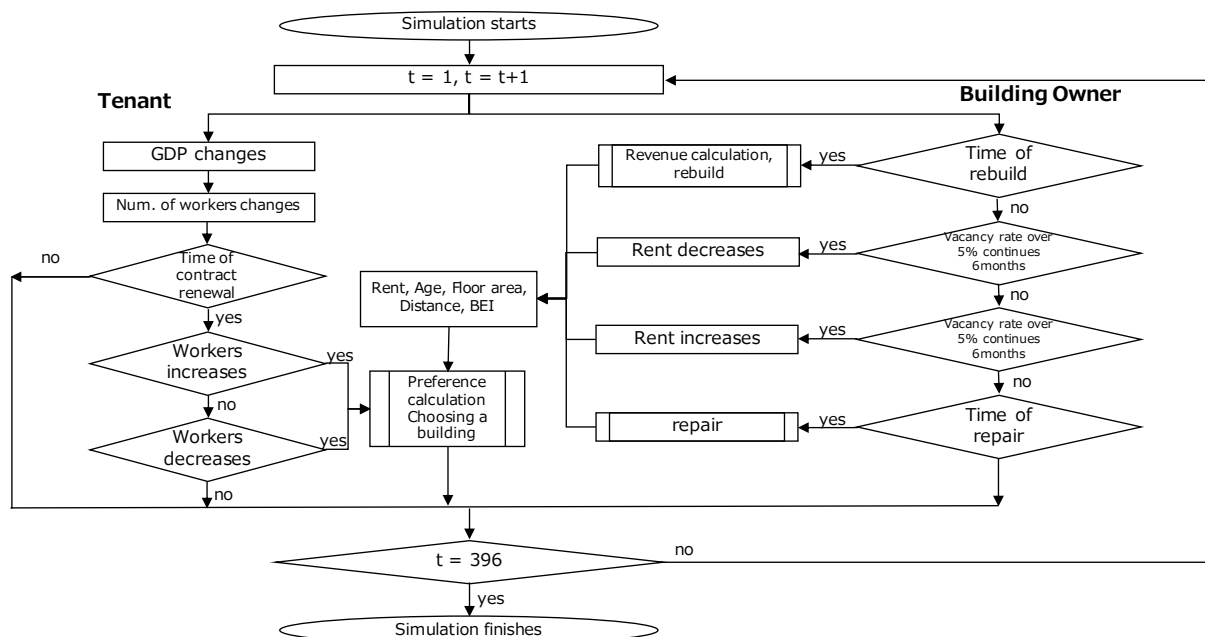


Figure 1. flow of the model.

2.1 Explanation of model

OAs and TAs act to satisfy their own requirements. OAs change their rent, repair and rebuild to maximize their profit in the life cycle of their buildings, and TAs decide which building to move in or relocate according to rent, total floor space, Building Energy-efficiency Index (BEI), distance from the station, etc. of each building. From this model, we can know whether the energy saving measures will function effectively in the buildings' lease market. We created a virtual field for simulation with 200 OAs and 2674 TAs. We evaluated the penetration of green buildings through the decrease of average BEI. The simulation period is 500 months.

2.2 Building Owner Agent

According to an interview survey and research by Japan Real Estate Institute, OAs decide to change their rent from the change of vacancy rate, and they reconstruct and renovate based on the age of buildings. OAs rebuild their own buildings, predicting that the lifecycle benefit will be the highest. The profit in the life cycle is calculated as shown in equation (1). If the type of introduced equipment is energetically efficient, the running cost decreases, but the initial cost increases. Also, whether energy-efficient buildings are popular or not in the simulation field, (that is, average vacancy rate is low or high), predicted revenues from rent will increase or decrease. The new amount of rent at the time of rebuilding is basically the average rent at that time, but if the expected margin of the life cycle is less than the standard, it will be set up at the cheapest rent within the range that meets the standard. The timing of rebuild is 50 years.

$$NB_{i,BEI} = -IC_{i,BEI} + (B_{i,BEI} - RC_{i,BEI})P_{pay} \quad (1)$$

$NB_{i,BEI}$: Net Benefit when building i is the BEI

$IC_{i,BEI}$: Initial Cost when building i is the BEI

$B_{i,BEI}$: annual Benefit from rent when building i is the BEI

$RC_{i,BEI}$: annual Running Cost when building i is the BEI

P_{pay} : payment calculated period

The rent of a building during the time of normal operation changes depending on its vacancy rate. the rent decreases if the vacancy rate is high and it increases if the vacancy rate is low.

Facility renovation related to building energy performance is also modeled. OAs introduce energy-efficient facilities if the vacancy rate of their own is high and the vacancy rate of surrounded high energy performance buildings is low. The update time and change point of each repair equipment and the primary energy consumption base unit reduction amount are as shown in the table. The update time, change point, and the reduction of energy amount in a unit are as shown in Table 1., which are calculated from previous research of *Building and Equipment Long-life Cycle Association* [10].

Table 1. the setting of facility renovation.

equipment	update period(year)	energy reduction amount (MJ/m ²)
Heat pump	20	83.7
Pump	20	97.7
Air conditioner	20	195.4
Light	20	139.6
Elevator	30	14.0

2.3 Tenant Agent

Each TA has their own workers, and the number of workers depends on the change of GDP [11]. When their workers increase or decrease by more than 2% and the time of contract renewal (every 2 years) comes, TAs decide to move to a new building [12].

When they need their new office, we consider this discrete selection problem as a multinomial logit model. The utility to each building (u_i) depends on the sum of definite value v_i and error value ε_i (Equation (2)). For easy calculation, in this model, we processed ε_i as no effect, thus the probability that the building i is selected only depends on v_i (equation (3)). v_i in equation (3) is according to equation (4).

$$u_i = v_i + \varepsilon_i \quad (2)$$

$$p_i = \frac{\exp(v_i)}{\sum_j \exp(v_j)} \quad (3)$$

$$v_i = \alpha_0 + \alpha_{Rent}Rent_i + \alpha_{Area}Area_i + \alpha_{Age}Age_i + \alpha_{Distance}Distance_i + \alpha_{BEI}BEI_i \quad (4)$$

In equation (4), v_i consists of 5 elements of building; Rent, Total Floor Area, Age, Distance from the nearest station, and BEI. These elements influence the probability of TA's choosing office. All elements have different units, thus they are processed to be standardized to equally estimated. The parameters of equation (4) (α_0 , α_{Rent} , α_{Area} , α_{Age} , $\alpha_{Distance}$, and α_{BEI}) are adjusted so that the calculated value simulates the actual value. In this study, actual value of rent and vacancy rate is used for the evaluation in order to define the parameters. The weight of parameters is Table 2 and the result of evaluation of calculated value of rent and vacancy rate is in Fig. 2. We can read from Fig. 2 that rough value of rent and vacancy rate simulates the actual value, although it needs about 60 months for most of TAs to move in any of the buildings. α_{BEI} changes according to an adopted measure (described in detail in 2.6: *Energy policies discussed in this paper*).

Table 2. Identified parameters of TAs' utility.

α_0	14.48
α_{Rent}	-0.31
α_{Area}	0.81
α_{Age}	-0.33
$\alpha_{Distance}$	-0.20
α_{BEI}	-

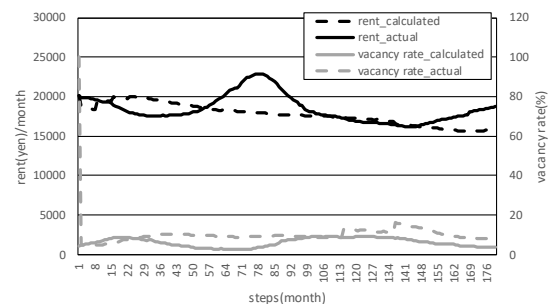


Figure 2. Comparison of calculated and actual value.

2.4 Setting of two divided areas

When promoting energy conservation, it is necessary to consider not only its good points but also the harmful effects of forcibly promoting the energy saving. In this research, we consider this risk by dividing the 200 buildings into two areas as shown in Figure 3. Area A is an area where measures are applied, and the other side B is not applied but fixed area. As a result, if the measures in A are appropriate, tenants gather in A and the average rent increases or the vacancy rate decreases, but if inappropriate, the tenant flow out to B and the average rent A declines or the vacancy rate increases. Evaluation as to whether the measures are appropriate can be judged not only from the energy performance of the building but also from the attraction of the area. In this paper, the average rent and average vacancy rate of the area were regarded as the attraction of the area. The comparisons are separate for rent and vacancy rate, and evaluation with quantitative indicators that considers both rent and vacancy rates is for future study.

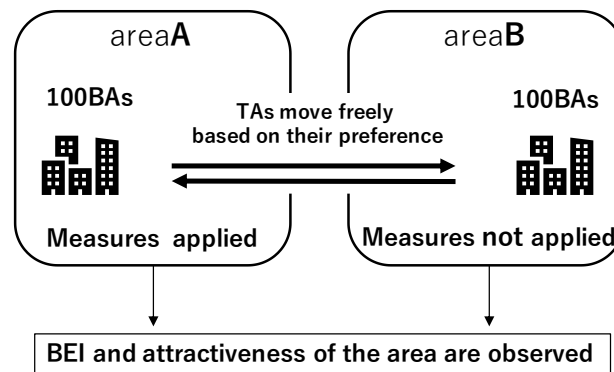


Figure 3. Division into two areas.

2.5 Initial settings

Table 3 is the initial setting of OAs. The characteristics of each OA are determined by calculation so as to simulate the actual statistics of buildings in office area in Tokyo [13]. The number of TAs is determined by the statistics on the ratio of tenants to the number of buildings. The number of workers in each TA is determined according to the statistic on the percentage of workers to the number of tenants. The number of OA is 200, the number of TA is 2674 and the whole workers are 79936.

Table 3. Initial settings of buildings.

-	Area(m ²)	Age(month)	BEI(-)	Distance(m)
avg	1583	337	0.904	181
max	11612	666	1.339	458
min	631	9	0.848	92

2.6 Energy policies discussed in this paper

We applied 3 policies in this simulation. Compliance with energy efficiency standard is expressed as regulatory measures, and recognition of BELS is expressed as incentive measures under the Building Energy Efficiency Act. Subsidy for equipment is considered in order to reduce initial cost of rebuild.

The energy efficiency standard compliance is applied when OAs rebuild their buildings. It prohibits constructing new buildings over the standard BEI, thus OAs must build the most beneficial office under this limitation. Currently, the standard BEI is 1.0, and we considered the values 1.0, 0.8, and 0.6 in the model.

We set up spread of BELS in the model as TAs' parameter to BEI increases as BELS spreads. That is, α_{BEI} in equation (4) increases when TAs move to another buildings. The value of α_{BEI} is 0, 0.3, and 0.6 in this model.

When OAs rebuild their buildings into more energy-efficient ones, subsidy is given. Subsidy helps the initial cost of green buildings. In real, the total amount of subsidy in an area is limited and not all buildings satisfying the requirement of aid can get the subsidy, but in this model, all energy efficient buildings can receive the subsidy for the easy calculation. Equation (5) is applied when the subsidy is effective. $IC_{BEI,Sub}$ is assigned in $IC_{i,BEI}$ in equation (1). Considered value of $p_{Subsidy}$ is 0, 1/3, and 2/3. In this study, in addition to each single 3 measures, the all combinations of them are considered, thus the whole considered patterns are $3 \times 3 \times 3 = 27$ patterns as shown in table 4.

$$IC_{BEI,Sub} = IC_{BEI} - (IC_{BEI} - IC_1) \times p_{Subsidy} \quad (5)$$

$IC_{BEI,Sub}$: Initial cost considering the subsidy

$p_{Subsidy}$: ratio of subsidy support

Table 4. Discussed patterns of policies.

measure	values			Num. of patterns
Standard	1.0	0.8	0.6	3
α_{BEI}	0	0.3	0.6	3
$p_{Subsidy}$	0	1/3	2/3	3

Total: 27 patterns

3. Results and discussion

3.1 Effect of single policy on green building penetration

Firstly, we consider the results of each policy. Figure 4. is the result of average BEI in each steps when standard BEI changes, Figure 5. is the result of α_{BEI} changes, and Figure 6. is the result of $p_{Subsidy}$ changes. These results are all from the area A only. As the Figure 4. shows, energy-efficiency standard compliance is effective when the value is 0.6. Even if the standard is 1.0, the best $NB_{i,BEI}$ tends to be around 0.6, so not many OAs is influenced by the standard when it is 0.8 But when the standard is 0.6, all the OAs is forced to be BEI 0.6, and some OAs decide to build around 0.4, so the average improves. For this reason, especially, when the standard becomes 0.6, average BEI decreases sharply. In contrast, when α_{BEI} changes, average BEI does not improve. This is because the utility of TAs to energy-efficient buildings does not influence effectively because the effect is indirect on the calculation of rebuild or repair, and it does not have a force to OAs, so the effect is not so strong.

Fig. 6 show that when the ratio is 1/3 it does not have effect to the average BEI but when the ratio is 2/3 the BEI improves. This is because ratio of 1/3 cannot bear the increment of initial cost of green buildings even though running cost relieves, while the 2/3 can bear the increment of some buildings.

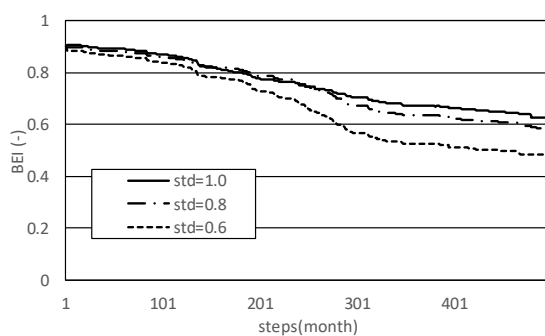


Figure 4. Change of BEI when std changes.

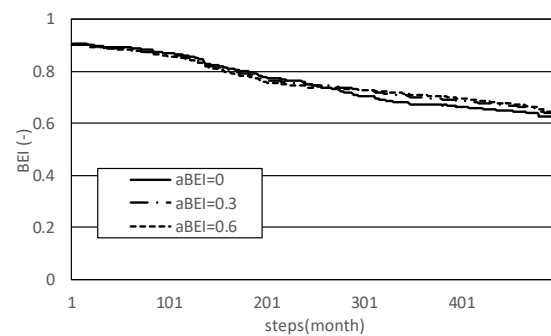


Figure 5. Change of BEI when α_{BEI} changes.

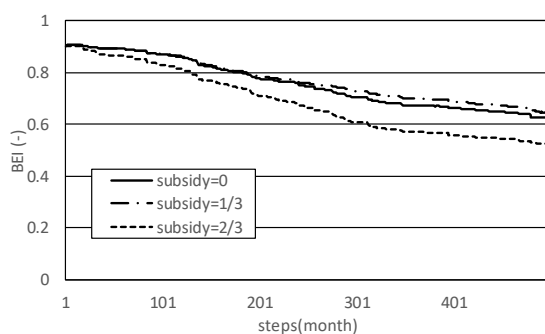


Figure 6. Change of BEI when $p_{Subsidy}$ changes.

3.2 Effect of combination of policies on green building penetration

We conducted 27 patterns of combinations of policies, but because of the limit of space, we introduce some important results only.

the combinations of the three policies have an effect to the average rent. Figure 7. is a result when standard = 0.6, $\alpha_{BEI} = 0.6$, and subsidy = 1/3. As the figure shows, When the BEI in the area A is lower than that in the area B, rent_A gets higher than that of rent_B. If the preference to energy-efficient building is enough and the BEI_A is lower than the BEI_B, TA's popularity to the area A results in rent_A getting higher than rent_B. This trend is also recognized from Figure 8.; change of vacancy rate. VR_a is lower than VR_b because of the difference of average BEI. Furthermore, When BEI in area_A improves largely, area_B also promotes energy saving. We can understand this trend from Fig. 8; Box plot of BEI at 500 months under the standard 0.6 and α_{BEI} 0.3.

As Figure 9. shows, when subsidy = 2/3, BEI in area_B is lower by around 0.1 than the case of subsidy= 0, 1/3. This can be thought that the higher rent of low BEI in area A influences the calculation of net benefit of rebuild in area B. From this result, we can say that successful energy conservation in an area can increase the appeal of the area, and can also have an effect in other areas. In contrast, Regarding rents, area A is affected by the decline in rent in area B, and rents in area A have also declined slightly despite the vacancy rate being lower than area B like Figure 10.

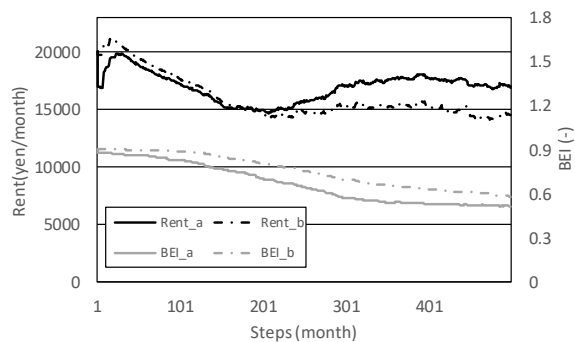


Figure 7. Change of Rent and BEI
standard = 0.6, $\alpha_{BEI} = 0.6$, subsidy = 1/3.

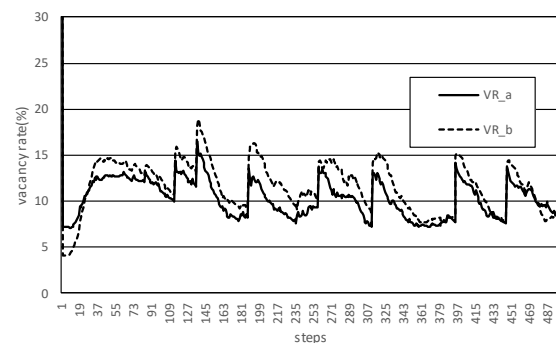


Figure 8. Change of vacancy rate
standard = 0.6, $\alpha_{BEI} = 0.6$, subsidy = 1/3.

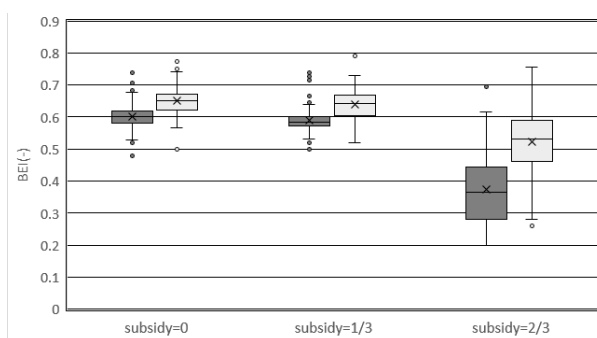


Figure 9. Box plot of BEI at 500 steps
standard = 0.6, $\alpha_{BEI} = 0.6$.

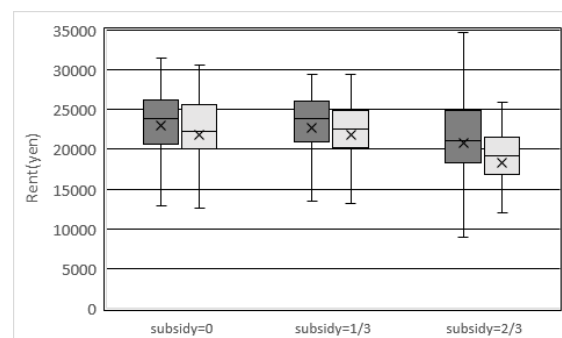


Figure 10. Box plot of BEI at 500 steps
standard = 0.6, $\alpha_{BEI} = 0.6$.

Next, we focus on the difference between the different combination. Figure 11, Figure 12, and Figure 13 are the BEI at 500 steps. From Figure 11, we can understand that Irrespective of the value of α_{BEI} , the greater the ratio of subsidies, the more energy saving progresses. This tendency is observed similarly when the standard is 0.8. Also, there is no big difference when the standard is 0.8 and 1.0. The reason of this trend is that the net benefit when OA rebuild is usually the largest around 0.7, but

when the subsidy 2/3 is applied, the net benefit is likely to be the highest at the BEI largely under the standard value. For example, under the situation in standard 0.8, α_{BEI} 0.6, and subsidy 2/3, the most frequent BEI after the 500 steps finished is between 0.5 and 0.6 (Figure 14). We can say that The effect of BELS is not very large, while the effect of subsidies is great to advance the energy saving of buildings.

Another point from these graphs is that as the standard becomes stricter, the BEI in the case where the subsidy is 0 gradually improves, but the BEI in the case of the subsidy of 2/3 is almost the same. From this point, it can be said that strict standard is not necessary when subsidies can be sufficiently contributed, but it can be said that it is necessary to set severe standards in order to promote energy conservation when subsidies are not sufficient

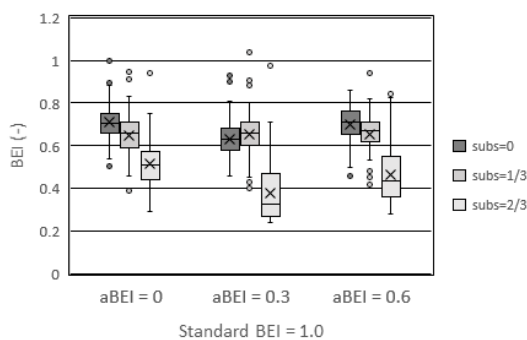


Figure 11. Box plot of BEI at 500 steps
Standard BEI = 1.0.

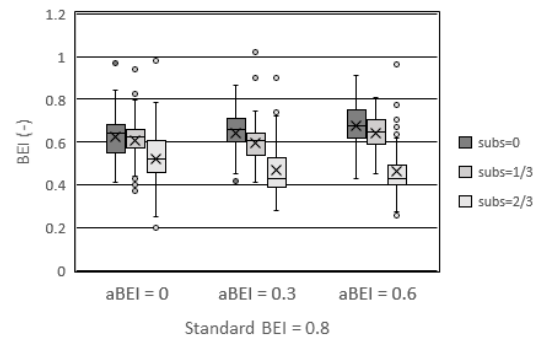


Figure 12. Box plot of BEI at 500 steps
Standard BEI = 0.8.

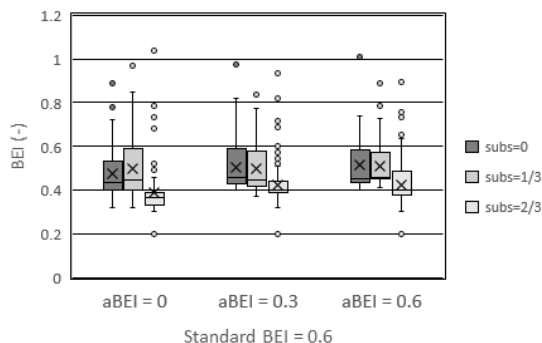


Figure 13. Box plot of BEI at 500 steps
Standard BEI = 0.6.

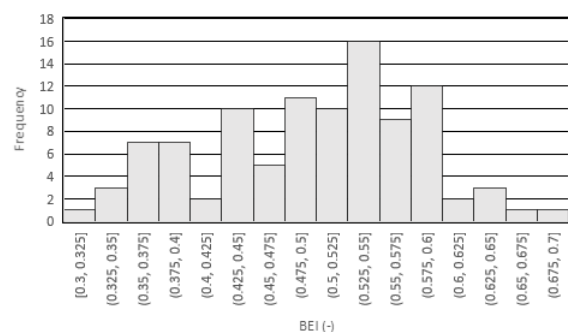


Figure 14. frequency of BEI
Standard BEI = 0.8, α_{BEI} = 0.6, subsidy = 2/3.

4. Conclusion

In this study, using the agent-based model, we constructed a virtual space for simulation made of building owners and tenants. In addition, we divided the space into 2 areas so that we could considered the attractiveness of the area. Then using it, we analyzed the effect of each energy saving measures and their combinations. As a result, we found that it is difficult for BELS only to advance energy conservation, but some amount of the standard and subsidy progresses energy saving greatly. We also found that the strict standard is not necessary when subsidies can be sufficiently contributed, but it can be said that it is necessary to strict standards in order to promote energy conservation when subsidies are not sufficient. Furthermore, we analyzed the relation of area A and area B. As a result, we found that adequate combination of measures increases the attractiveness of area and influence the other area the effect of energy saving.

Although we could find some important point to the future policy making, we have to pay attention to the specific value of each measures because this model has simplifications and assumptions to some extent. Especially relation between multiple areas is very complex and complicated in real world, thus more detailed construction of model is needed. For further investigations and analyzes, we will consider more detailed and large-scale simulation, and construct more realistic model.

References

- [1] United Nations 2015 Paris agreement Article2 1 (a)
- [2] United Nations Framework Convention on Climate Change 2015 Submission of Japan's Intended Nationally Determined Contribution
- [3] Ministry of land, infrastructure, transport and tourism of Japan 2016 Overview of The Building Energy Efficiency Act
- [4] Porse E Joshua D Hannah G Zoe E and Stephanie P 2016 Structural, geographic, and social factors in urban building energy use: Analysis of aggregated account-level consumption data in a megacity *Energy policy* Vol 96 179-192
- [5] Huang B, Volker M. and Yong G 2016 Analysis of existing building energy saving policies in japan and china. *Preventing smog crises* Vol 112 1510-1518
- [6] Gilbert N 2008 Agent-based models *Sage*.
- [7] Silvia C and Rachel M. K 2016 Assessing the impact of policy interventions on the adoption of plug-in electric vehicles: An agent-based model *Energy Policy* Vol 96 105-118
- [8] Liang X, Tao Y, Jingke H and Geoffrey Q S 2019 Making incentive policies more effective: An agent-based model for energy-efficiency retrofit in china *Energy Policy* Vol 126 177-189
- Building and Equipment Long-life Cycle Association. (2014). Data Collection for Building Lifecycle Management Revised 4th Edition
- [9] Masuda T 2018 Decision making of tenants and building owners at office building and prediction of energy-saving policies. *Master thesis Summaries. Department of architecture, graduate school of engineering, the university of Tokyo* 221-224
- [10] Building and Equipment Long-Life Cycle Association 2014 Database to Manage Building Life Cycle for LC Evaluation, Long-Term Repairment Plan, Diagnosis, Asset Evaluation and ER
- [11] Ministry of Health, Labor and Welfare of Japan 2013. An analysis of labor economics in 2013
- [12] Mori Building 2017 Survey on office needs of the 23 wards of Tokyo
- [13] Lim J 2017 Impact of mandating compliance with energy conservation standards and raising standards of obligation on changes in energy consumption in the future (part 1) *Architectural Institute of Japan* 789-790